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Synopsis of Early Field Test Results from the Gravity Gradiometer Survey System

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ABSTRACT

Initial airborne and surface testing shows that the earth's gravity gradients can be usefully measured both from an aircraft and an automotive vehicle.

1. BACKGROUND

The Gravity Gradiometer Survey System (GGSS) is a mobile unit that measures the five independent gradients of Earth's gravity vector. The system includes three gradiometer instruments and ancillary inertial hardware mounted on a local-level stabilized platform, a navigation system, and electronic support equipment. The entire apparatus is housed in a van that has the capability of surveying along roadways or of operating while being carried in a C-130 cargo airplane. Data processing includes an initial stage of demodulation, filtering, self-gradient corrections, acceleration sensitivity compensations and accounting for other environmental influences. Secondary postprocessing to obtain gravity component estimates includes bias estimation (using cross-over constraints and tie-point data), followed by along-track integration and downward continuation (for the airborne case) performed as an optimal, minimum variance estimation process. The tests to assess the survey accuracy of the GGSS were conducted primarily in the Texas-Oklahoma Panhandle area where the terrain is very smooth while the gravity signature is moderately pronounced. About 120 tracks were flown at nearly constant altitude (about 1000 m above ground) in a regular grid of north-south, east-west tracks. Each track is 315 km long with a nominal spacing of 5 km between tracks. In addition, surface testing was conducted which included two traverses performed on the same highway route.

2. AIRBORNE TEST DATA RESULTS

From the airborne GGSS test data collected in spring of 1987, a total of 56 distinct tracks were considered by the gradiometer operator to be appropriate for further analysis. Upon examination, the need to edit the data for erratic flight trajectory, loss of signal, and excessive noise was apparent and resulted in the elimination of 21 tracks from further processing. The resulting "edited" 35 tracks show sporadic occurrences of mostly-isolated spikes in the measured gradients. The spikes were removed by detection with a matched filter and deconvolving with the impulse response of the demodulator filter.

Based on their length and orientation with respect to the other edited tracks, 20 of the 35 tracks were selected for estimating gravity disturbances. The gradient data along these tracks were resolved into an appropriate local-level reference frame. Five-minute by five-minute gravity disturbances along each track were then estimated using a Kalman smoothing algorithm. The smoother included error models for the GGSS white noise floor [as identified from Power Spectral Densities (PSDs)], the gradient bias uncertainty (based on track length and PSD), and the uncertainty associated with each tiepoint (rms uncorrelated error of 2.0 mgal). Single-track spectral analysis indicated that the GGSS contributed noise power ranging from 350 to 1700 E^2/Hz (double-sided PSD). Gravity disturbance estimates were compared with corresponding quantities derived from an available five-minute by five-minute mean gravity disturbance truth dataset. The truth values were interpolated along each GGSS track using a four-point bilinear smoother. Along the best tracks, the vertical component of the gravity disturbance vector could be recovered with an rms error of about 5 mgal for tiepoints over 200 km apart. The rms accuracy improved to 2 to 4 mgal when the tiepoint spacing was reduced to about 90 km.

Thirteen of the foregoing 20 tracks were situated in sufficiently close proximity (Figure 1) to permit investigation of the increased accuracy obtainable for multi-track analysis. The TASC template algorithm (Refs. 1, 2) was used to perform gravity disturbance estimation within the areas bounded by the intersections of the 13 tracks. The template algorithm was used with the Clinton-Sherman Attenuated White Noise Statistical Gravity Model (Ref. 3), data-derived error models for the GGSS measurements, and the rms uncertainty of the tiepoint values. A summary comparison of these multi-track estimates with corresponding surface truth values is presented in Table 1. The two distinct cases considered were 1) tiepoints at the ends of each track, and 2) tiepoints only at the centers of the boundary tracks. For each case, the actual rms error agreed well with the predicted rms errors provided by the template algorithm covariance equations (Ref. 4).

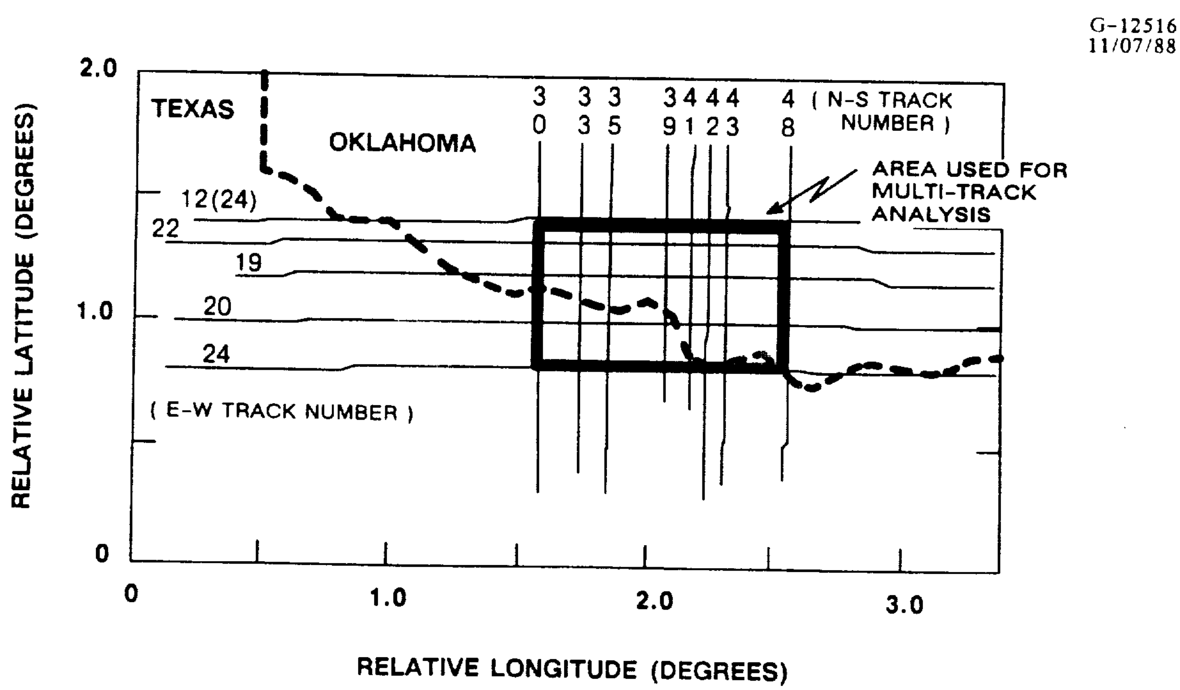

Figure 1. Tracks and area selected for multi-track analysis.

Table 1. Summary of multi-track comparisons.

CASE	RMS ERROR: ALL POINTS (mgal)		RMS ERROR: NON-TIE POINTS (mgal)		WORST CASE ACTUAL ERROR (mgal)
	PREDICTED	ACTUAL	PREDICTED	ACTUAL	
Tiepoints at Ends of Each Track	1.93	1.64	2.33	2.16	3.72
Tiepoints at Centers of Boundary Tracks	4.34	3.27	4.53	3.44	8.77

Deflections of the vertical were estimated along several of the tracks using line integration at altitude. In Figure 2, GGSS estimates for two selected tracks are compared with surface truth data derived using Vening-Meinesz integration. Source data consisted of a two-degree "square" inner zone containing 1'x1' mean anomalies, a middle zone having a six-degree by eight-degree outer perimeter with 5'x5' mean anomalies and an outer zone consisting of 30'x30' mean anomalies over the rest of the earth. The data was provided by DMA.

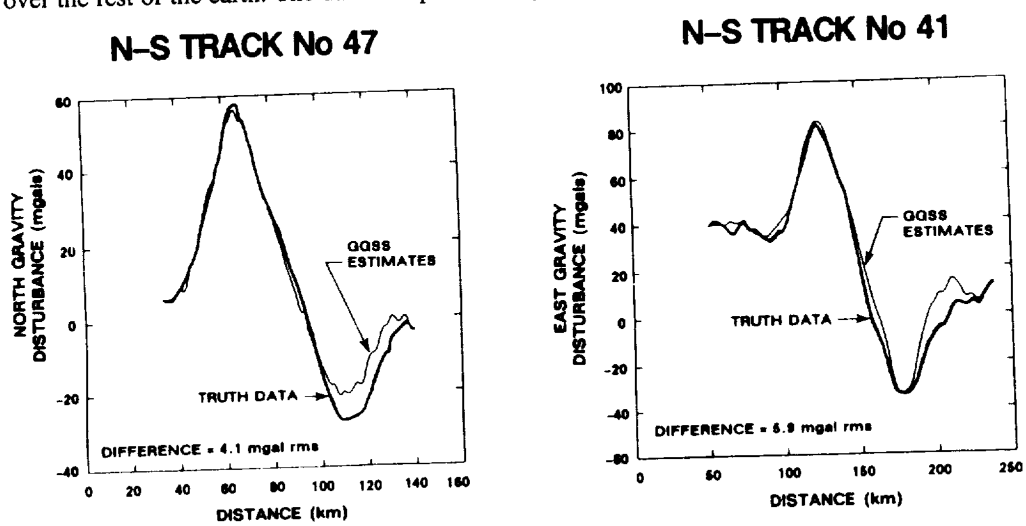

Figure 2. Horizontal gravity disturbance components at the surface.

3. SURFACE TEST DATA RESULTS

Surface GGSS testing was performed along a 53 km section of paved road near the Clinton-Sherman airfield. Two tracks of repeat traverse data (one taken on 6 June 1987 the other on 9 June) were processed by the gradiometer operator. The data quantities of interest available for each track were: time, fifth-wheel aided inertial latitude and longitude, altitude, heading, and the inline and cross gradients for each of the instruments in the triad. As with the airborne data, isolated spikes were present in the gravity gradients.

In addition to spike removal, navigation system performance was analyzed to assure that position misregistration errors of the relatively high frequency surface gradient field were not mistaken as GGSS noise (Ref. 5). Kalman-Smoothed estimates of all three components of the gravity disturbance vector were performed. The vertical and along-track components are presented in Figure 3. For the repeatability analysis shown in Figure 3, the tiepoint spacing for the deflection of the vertical data was 46 km and the rms accuracy was 0.5 arcseconds. Vertical disturbance tiepoints, spaced at 52.8 km, were assigned an rms accuracy of 2.0 mgal.

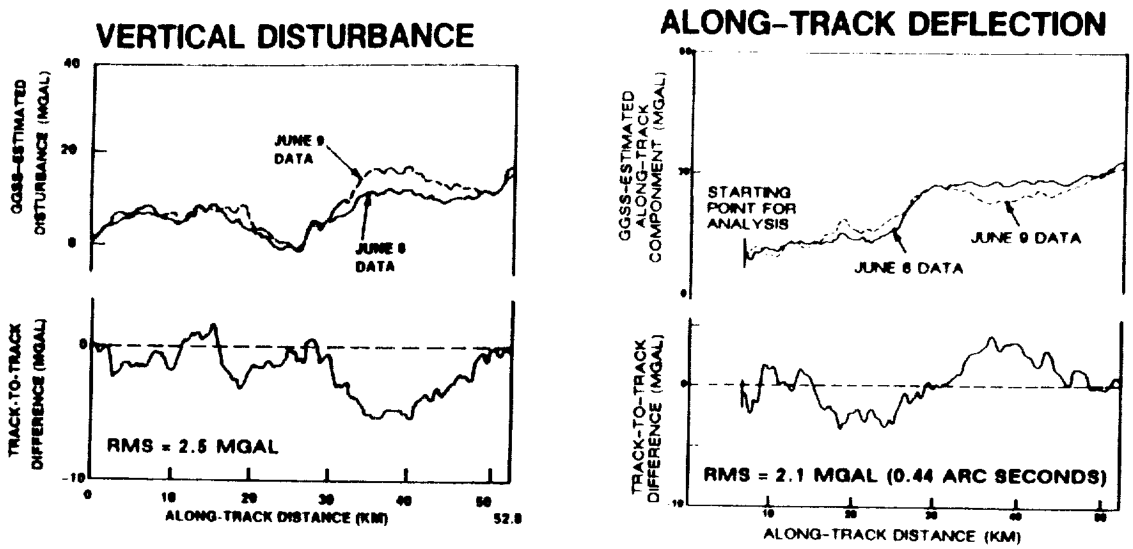

Figure 3. Kalman-smoothed gravity disturbance estimation for individual surface tracks.

4. CONCLUSIONS

Although the amount of data yielded by the tests was modest, it was sufficient to demonstrate that the full gravity gradient tensor had been successfully measured from moving platforms both in the air and on the surface. The measurements were effectively continuous with spatial along-track resolution limited only by choice of integration lengths taken to reduce noise. The airborne data were less noisy (800 E^2/Hz typical) than were GGSS measurements taken at the surface (5000 E^2/Hz typical). Single tracks of surface gravity disturbances recovered from airborne data were accurate to 3 to 4 mgal in each component of gravity when compared to 5'x5' mean gravity anomalies over a 90 km track. Multi-track processing yielded 2 to 3 mgal when compared to 5'x5' mean anomalies. Deflection of the vertical recovery over a distance of 150 km was about one arcsecond.

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